Review of potential environmental consequences of the British Petroleum Deepwater Horizon well blow out spill, April 2010.

Background

An unknown but enormous quantity of crude oil is being released into the Gulf of Mexico from a depth of 5,000ft in the Mississippi Canyon 252 lease block (28°44.20'N, 88°23.23'W). There are many different ecosystems in the Gulf basin, and the extent to which they will be impacted depends on how much oil is released, where it goes, and also how it is treated. Mitigation can take the form of physical barriers or booms that block surface slicks and prevent the oil washing up on shore, igniting slicks to burn them from the surface, and applying dispersant chemicals that break down the surface slicks and allow them to sink in the water column.

Oil spill dispersants do not reduce the total amount of oil entering the environment; they simply change the chemical and physical properties of the oil, thereby changing its transport, fate, and potential effects. Dispersants also contain potentially dangerous compounds, but the chemistry of each brand is proprietary so the toxic effects are unknown. Small amounts of oil will disperse naturally into the water column through the action of waves and other environmental processes. The objective of applying dispersant is to increase the amount of oil that physically mixes into the water column, reducing the potential that a surface slick will contaminate shoreline habitats and fauna, or impact organisms that come into contact with the water surface (birds, marine mammals, turtles etc). However, by promoting dispersion of oil into the water column, dispersants increase the potential exposure of water-column and benthic biota to spilled oil. Dispersant application therefore represents a conscious decision to increase the hydrocarbon load on one component of the ecosystem (e.g., the water column) while reducing the load on another (e.g., coastal wetland). This trade-off reflects the complex interplay of many variables, including the type of oil spilled, the volume of the spill, sea state and weather, water depth, degree of turbulence (mixing and dilution of the oil), and relative abundance and life stages of resident organisms (1). The ultimate fate of dispersant-oil emulsions is poorly understood, particularly at the depths that they are being applied for the BP spill.

It is clear that there will be serious environmental consequences no matter what actions BP and other entities take, and they are now in the unenviable position of deciding which ecosystems they will sacrifice to try and reduce impacts to others. Below is a brief overview of the fate and toxicity of oil in the marine environment, and ecosystems/species that are particularly vulnerable to damage under two regimes: with and without the use of dispersant chemicals and other mitigation efforts.

Oil comes in many different forms, and each has a different set of physical and chemical properties, which influence the fate and toxicity once it is released into the environment. If the slick is not dispersed, it will end up on shore, probably at several different locations, with different pollution severity. This document will not focus on the effects of oil on shoreline habitats, but if large quantities of hydrocarbon are washed ashore, and ultimately flushed into the mouth of the Mississippi, it would add to the carbon and nutrient load that generates the annual dead zone.

Dispersal of oil by prevailing currents

The hydrography of the Gulf of Mexico is very complex; the currents near the coastline move north along the Florida coast and west along the northern Gulf States, but further offshore, the dominant feature is the loop current, which enters through the Yucatan Channel from the Caribbean Basin. The current creates a loop in the eastern Gulf with an anticyclonic circulation, and the power of this current creates complex warm and cold core eddies, which spin off to the west in a fairly unpredictable fashion. The eastern part of the loop flows into the Florida Strait and becomes the Florida current as it enters the Atlantic and joins with the powerful Gulf Stream. There is a very high probability that some of the non-dispersed surface oil (and some of the subsurface dispersed oil) will enter the Gulf Loop Current, currently only 30-60 miles from the observed surface slicks. The loop current can travel at speeds up to 1-2 m/s. Outlying plumes of surface oil slicks and patches of tar balls, if entrained into the Loop Current, could be carried towards the coral reefs, mangrove islands, and seagrass beds of the Florida Keys, then up towards Miami and potentially further up the East Coast as far as North Carolina. Fortunately, warmer waters of the Loop Current and Gulf Stream would increase the volatility of the oil, and the fast moving turbulent water would act on the thinner oil to disperse a portion of it into the upper water column, although the magnitude of this effect is unknown.

Use of dispersants

Adding dispersants to oil is a common practice to reduce surface slicks and protect shorelines; these chemicals change the physical and chemical properties of the oil and allow it to enter the water column, thereby exposing water column and benthic fauna to potentially toxic effects of the treated oil, and the dispersants themselves. Because natural weathering of the oil changes its properties, there is a small application window for dispersants to be effective. This is generally within 12-48 hours so dispersants would only be applied in the fairly close vicinity of the spill. This would not directly impact land masses, but sensitive deep sea habitats are close (~ 65 km) to the spill site. There is an extensive deep water coral habitat within the Viosca Knoll lease block 826 (29^{o}09.33'N, 88^{o}01.47'W), that lies beneath the potential surface slick. In addition, the immediate impact to water column fauna and the long term effects from sequestration in the soft sediment and hard bottom benthos are unknown. Given the location of the spill, if dispersants are used only within the recommended 2 day time window, they will not directly impact sensitive coastal habitats. Where the dispersant-laden water mass will end up however, is open to speculation. *The New York Times* reports that Corexit can bio-accumulate and persist in sediment and in the water column (where it could impact larvae and other plankton) for decades, especially in deep water where low temperatures can inhibit biodegradation.

Effect of oil on the marine environment

Aromatic hydrocarbons are the most toxic of the major classes of compounds in petroleum. The acute toxicity of crude and refined petroleum to aquatic organisms correlates directly with the concentration of light aromatic hydrocarbons (benzene through phenenthrene). Chronic effects of petroleum are attributed primarily to 4 and 5-ring aromatic hydrocarbons (polycyclic aromatic hydrocarbons or PAHs), some of which are well-known carcinogens; however, because of their low solubility, aromatic hydrocarbons with four or more rings rarely exist in acutely toxic concentrations. At the other extreme, the single-ring aromatic hydrocarbons (benzene, toluene, ethylbenzene and xylenes), are volatile and are generally lost rapidly from water through evaporation. The naphthalenes and phenanthrenes, which are slightly soluble and relatively persistent, contribute most to the toxicity of crude and refined petroleum. Heterocyclic compounds are also abundant in many crude oils and probably contribute to their toxicity (3).

The water soluble fractions (WSF) and oil-in-water dispersions (OWD) of crude oils were found to be considerably less toxic to the study species (six common Gulf of Mexico invertebrates and fish), than those of refined oil (4). In a similar study (5) the level of BTEX (benzene, toluene, ethylbenzene, xylene) was an order of magnitude higher in the WAF than in the dispersed oil mixtures, suggesting that the BTEX compounds were the source of toxicity in the WAF exposures, whereas naphthalenes may have been the primary cause of toxicity in the dispersed oil exposures. The dispersant itself (Corexit 9527) was acutely toxic, and was especially lethal to oyster larvae, but not much more so than the WAF and OWD treatments. In most exposures to all of the treatments, the majority of the mortality occurred within the first 24 hrs. Longer term effects on growth in white shrimp indicate that survival from the acute poisoning does not indicate the animals are healthy. In the first study the OWD of the crude oil lost 80-90% of the toxic water soluble hydrocarbons in 24 hours, and in the second, the volatile toxic components were undetectable after ~6 hours in both oil water soluble fractions and dispersed oil mixtures from the Gulf of Mexico.

In summary, there was no clear indication that any of the treatments were consistently more lethal than the other, and the greatest difference in toxicity arose from the type of oil, rather than whether dispersants were used or not. This conclusion was supported by a similar study on two fish and one shrimp species where oil and dispersant mixtures were equal or less toxic than oil only treatments (6). After a spill of fuel oil off the coast of Spain, bivalve and urchin embryos showed complete lack of development when exposed to seawater collected within days of the spill, and some toxicity persisted for 2 months. In contrast, embryos developed normally in elutriates from contaminated sand, despite the presence of small tar balls (7). In conclusion the volatile soluble fractions of oil are the most acutely dangerous to sub-tidal fauna, but although a great percentage of these may be readily lost to the atmosphere, particularly in warm active seas, the water column would still be polluted with oil emulsion, less volatile toxic aromatic hydrocarbons, and a tarry mess on the surface.

Particularly vulnerable ecosystems and species

This section reviews some published literature on the effects of raw and dispersed oil on marine organisms, focusing on those most likely to be affected by the BP oil spill in the Gulf of Mexico.

Pelagic fishes

In 2005, the Minerals Management Service produced a comprehensive analysis of the potential vulnerability of selected pelagic fish (adults and larvae) to oil spills from the offshore rigs in the Gulf of Mexico (8). This report documents known and predicted seasonal distribution of adults and larvae of bluefin tuna, yellowfin tuna, blackfin tuna, blue marlin, white marlin, wahoo, dolphin, blue runner, spotfin flyingfish, Atlantic flyingfish, ocean sunfish. Also included are selected members of the pelagic Sargassum community: sargassumfish, planehead filefish and tripletail. Most of these species produce large quantities of eggs with small yolk reserves; therefore, the larvae are small and are dependent on the plankton that concentrates near the surface. Bluefin tuna are the most commercially valuable species per pound and the only spawning ground for the western Atlantic is thought to be the Gulf of Mexico (8). Catch per unit effort data show that May produced the highest catches, but the fish tend to be further south and west than the current location of the oil spill. Unfortunately, bluefin tuna spawn during April-June, and their larvae concentrate in areas where currents or eddies encounter the shelf between the 100 and 1000 m isobaths in temperatures of 22-28^{o}C along the edge of the Loop Current. If the slick becomes entrained in the loop current, this would put the larvae in high probability of encountering oil. For yellowfin tuna, the probability of their larvae encountering the slick is high; larvae have only been found in May and June, and it is thought that the adults spawn on the seaward side of the Mississippi river plume and the larvae follow the frontal system, as will the oil slick. This is therefore a bad scenario for the 2010 year class of yellowfin tuna. For blackfin tuna, the seasonal distribution pattern would bring them into the vicinity of the spill in May-June. Their larval peak is May-July and they are most frequently found in the northern Gulf, east of Mississippi delta; the western edge of their distribution could coincide with the current slick position. Billfishes, including blue marlin are abundant near the Loop Current and their migration into the northeastern Gulf of Mexico is dependent on the position of the Loop Current, which is presently seaward of the location of the slick. However, if the oil becomes entrained in the loop current, blue Marlin would be vulnerable as they spend most of their time in the upper 10m of water, and with the heavy use of dispersants, it is quite possible that a toxic oil emulsion could contaminate to this depth. Spawning occurs in summer throughout their range. White Marlin are generally caught offshore of the oil slick, but it is possible that they are distributed further north into the spill area; they spawn in April-May. Wahoo are found in the vicinity of the slick during the summer months and are thought to spawn in June in the northern Gulf, where larvae and juveniles feeding in the surface waters. Dolphin are an important commercial and recreational species in Gulf of Mexico, and are frequently found associated with rafts of sargassum. In the winter they are confined to the warmer waters of the southern Gulf, but they move north during April-May and are found throughout the region until fall when they return south. Their highest abundance occurs from May-August and they feed near the surface, therefore could be greatly impacted by the spill. This species is fortunately very fast growing, reaching sexual maturity after one year, and they have an extended spawning period of several months from April-August. The eggs are buoyant, which would bring them into immediate contact with surface slicks. Flying fish, sunfish, and those species closely associated with sargassum rafts are most immediately vulnerable to floating surface slicks. Flying fish are found close to shore, and spawn in late summer, and the ocean sunfish ecology is not sufficiently well known to predict the distribution of the adults or larvae. There are many species of small fish and invertebrates that are closely associated with sargassum rafts, and many of them either spawn or recruit to the rafts during the early summer. Given the nature of the sargassum community, it is a safe assumption that if the rafts encounter oil, which will no doubt be circulating the Gulf for a very long time, the associated sargassum community will be severely impacted.

In summary, many of these species spawn during the summer months, and move further into the northern Gulf in the summer, following either the seasonal warming, or the more northerly intrusion of the loop current during the summer. Since this oil spill is so vast, it is reasonable to expect some of it to reach the loop current, and to spread further in the Gulf region. Given that these species feed close to the surface during one or more of their life history stages, it is also reasonable to expect that populations will be impacted, putting the 2010 year class at risk. Given the large number of variables in the behavior of oil released at depth, and the lack of understanding of population dynamics of pelagic marine species, it is almost impossible to predict long term impacts.

Cetaceans (whales and dolphins)

Three are ~28 species of cetacean documented for the Gulf of Mexico, six of which are on the endangered species list. This group of animals is vulnerable to surface slicks, since they have to pass through the water surface to breathe, and from feeding on contaminated food. Cetaceans feed at several trophic levels, each with a specific potential to retain and transfer hydrocarbon residues. Some benthic invertebrates, such as clams and worms, tend to concentrate petroleum hydrocarbons in their tissues. Fish, and to a lesser extent, crustaceans, metabolize and excrete hydrocarbons and so rarely become heavily contaminated (3). Therefore animals feeding at the top of a food chain such as toothed whales and dolphins are less likely to ingest oil-contaminated food than baleen whales feeding on planktonic or benthic crustaceans. Those feeding on bottom sediments where oil may eventually deposit after a spill have the greatest potential for ingesting oil-contaminated food.

A study by Davis et al (9) indicated that cetaceans in the northern Gulf of Mexico tend to be found in or near hydrographic features, which concentrate food stocks. The amount of potential prey for cetaceans may be consistently greater in the cyclone, confluence areas, and south of the mouth of the Mississippi, making them preferential areas for foraging, and may explain the ***presence of a resident, breeding population of sperm whales within 100 km of the Mississippi River delta***. The worst of the spill falls within this general area, and could potentially impact the habitat of these whales and their prey.

The effects of oil on marine mammals is summarized in a report commissioned by the Minerals Management Service (10), and includes potential likelihood and impacts of exposure to different groups of seabirds, cetaceans and other marine mammals that have to break through the surface to feed or breathe and are therefore likely to come into direct contact with the slick.

Seabirds

Seabirds are often at greatest risk from exposure to spilled oil through various mechanisms including floating, diving consumption of contaminated food and fouling of colonies on shore. Birds also spend a lot of time preening to maintain their feathers, which is an additional ingestion route. Birds with fouled feathers are at risk of drowning or dying of hypothermia. Those that ingest oil may suffer from gastrointestinal inflammation, immune-suppression, abnormal metabolic functions and anemia, and other physiological problems. Even those birds treated and released from rehabilitation centers do not appear to fully recover; they suffer higher than normal mortality rates and generally fail to breed for one or more years (11). Effects of PAHs on breeding adults include reduced egg production and hatching, increased nest abandonment reduced growth and a variety of other biochemical responses (12). Studies from the Exxon Valdez spill in Alaska indicate that population recovery in seabird populations can be very slow; most taxa that were damaged during this spill had still not recovered nearly a decade later (13). This of course has long term implications for shorebird species, especially those whose populations are already threatened from other anthropogenic impacts.

Turtles

In the spectrum of threats facing sea turtles, oil spills do not rank very high. They are generally rare and affect a limited geographic area, and oil is not the most toxic material that could be spilled into turtle habitat. However, in 1979 a massive oil spill resulting from a drilling platform blowout in the Gulf of Mexico threatened one of the only known nesting beaches of a particularly threatened sea turtle, the Kemp's Ridley. The spill resulted in minor impacts to the Kemp's Ridley population, but a major tragedy was averted. There are 5 species of turtles found in US coastal waters, and all are threatened or endangered; the 1974 spill emphasized the tenuous existence for threatened sea turtles, and how a single catastrophic oil spill, such as the current BP incident, might serve as the synergistic "tipping point" that could prove devastating to populations stressed from other factors. A NOAA report released in 2003 (14) is a comprehensive overview of turtle life history, distribution, biology and vulnerability to oil contamination. The following key points are taken from the report: 1) Although surprisingly robust when faced with physical damage, sea turtles are highly sensitive to chemical insults such as oil, 2) Sea turtles are vulnerable to oil toxicity at all life stages: eggs, post-hatchlings, juveniles, and adults in nearshore waters, 3) Several aspects of sea turtle biology and behavior place them at particular risk, including a lack of avoidance behavior, indiscriminate feeding in convergence zones (leading to ingestion), and large pre-dive inhalations, 4) Oil effects on turtles include increased egg mortality and developmental defects, direct mortality due to oiling in hatchlings, juveniles, and adults; and negative impacts to the skin, blood, digestive and immune systems, and salt glands, 5) Response activities have the potential to adversely affect sea turtles, both on the water and on the beach. Probably the greatest potential for impact exists in beach related oiling and cleanup, which could disturb nesting females, nests, and hatching turtles, due to the large numbers of animals that could be affected in a relatively small area.

Pelagic habitats

The water column supports fauna such as seabirds, cetaceans and turtles that will be directly impacted by the oil slick because they frequently come to the surface, but the areas where these large fauna congregate are often due to increased productivity from hydrographic features such as divergence zones, eddy confluences and gyres. Oil is likely to be entrained in these features and subject such megafauna to direct chemical exposure, but a more subtle impact on pelagic systems would be a toxic effect on the lower trophic levels such as plankton, larval and adult stages of important species and the midwater community. This could not only undermine the trophic system, but also reduce the year class size of species that have larvae in the surface waters during this time period.

Sargassum and Associated Species

Once on the East Coast, oil could impact shallow bays, estuaries, and other coastal areas or remain in offshore eddies or in the Gulf Stream current. Another possible destination is for oil to move east out of the Gulf Stream into the Sargasso Sea at the heart of the North Atlantic Subtropical Gyre. Surface oil could remain in the calm waters under resident high pressure systems and within the subtropical convergence zone. Some have estimated that the Sargasso Sea alone already entraps 70,000 metric tons of tar within the gyre (not from the current spill). In a paper published in 1973, the authors analyzed pelagic Sargassum weed and associated macrofauna for their hydrocarbon content. All the organisms appeared contaminated with petroleum hydrocarbons with no regard to their positions in the food chain. While oil from the Deepwater Horizon spill that eventually settles into the Sargasso Sea is likely to be sparsely distributed, it could potentially impact many of the diverse species closely associated with floating pelagic Sargassum habitat, which is also quite common within the Gulf of Mexico and south Atlantic coastal regions. Many species of commercially important adult fishes (e.g. tuna, dolphin, wahoo and billfish) associate regularly with Sargassum, as do several seabird and turtle species. Sargassum weed is crucial habitat for the survival of hatchling and posthatchling hawksbill, green and loggerhead turtles. For their first year or longer, these hatchlings drift with the Sargassum, utilizing them for food and cover during a very vulnerable life stage. Turtles have been shown to exhibit no avoidance behavior in the presence of oil and often feed indiscriminately, especially in early life stages. Turtles of all age classes have been shown to forage on tar balls and other forms of oil when it is present in their feeding areas, particulary along weedlines and other types of convergence zones where it may accumulate (2).

Benthic habitats

There are many different types of sensitive benthic habitat in the GOM including 1) deep water corals on the slope of the northern GOM and west Florida shelf, 2) mesophotic coral reefs in the northern GOM (FGBNMS) and west Florida shelf (Pulley Ridge), 3) mesophotic rocky ledges on the Florida shelf that provide spawning habitat for commercial grouper and snapper species 4) shallow rock ledges that support many fisheries including octocoral and sponge harvesting, and 5) seagrass and sandy habitat that provides nursery and feeding grounds for abundant fish and invertebrate species (eg Florida panhandle, 1000 Islands in Florida Bay, Barrier island habitats of coastal Gulf states.

The principle differences between potential impacts on pelagic and benthic ecosystems are 1) many of the animals cannot move to avoid pollution 2) benthic habitats are the ultimate repository for particulate material falling out of the water column. While animals on or near the surface may suffer the acute effects of oil toxicity and slick pollution, the benthic communities could suffer less acute, long term, sub-lethal effects that are much harder to measure. In deep sea or high latitude areas where metabolic breakdown is slower, these effects may persist for a very long time. In 1969 a New England marsh was polluted with a large quantity of fuel oil, and almost 40 years later fiddler crabs living in the marsh showed lower densities, feeding rates and escape responses than those in an unpolluted marsh nearby (14). Some groups of benthic animals, particularly bivalve mollusks, lack the enzymes necessary for rapid metabolism of hydrocarbons and bioaccumulation may occur. Although the accumulation of aromatic hydrocarbons in adult mussels was not lethal (15), their tissues were sufficiently burdened that extracts were toxic to juveniles of the same species. This bio-accumulation could lead to negative socio-economic impacts on fishing communities that are dependent on shellfish harvesting.

Summary

The most toxic components of oil and oil-dispersant mixtures are the light aromatic hydrocarbons, the majority of which evaporate quickly; however this leaves heavier toxic hydrocarbons, other pollutants, colloidal oil (oil emulsion in water) and tar, which can cause severe and long term environmental damage.

Acute toxic effects are only a small part of the impact; persistence in the environment, bioaccumulation (in some species) and chronic physiological effects can cause sub-lethal impacts throughout the ecosystem for an extended time period, reducing their general health and making them vulnerable to other stressors.

Some particularly vulnerable ecosystems are within the oil spill contamination zone; a resident population of sperm whales has been documented in the general area of the slick (100km south of the mouth of the Mississippi) and the biggest known deep water coral ecosystem in the GOM is located within 65 km of the spill source (figure 1). If dispersants are used, or if oil naturally reaches this habitat, the effects are potentially damaging.

Marine birds are probably the most vulnerable of all animals to acute and chronic toxic effects of the oil.

Several of the commercially important large pelagic fish species spawn in the early summer and produce larvae that feed near the water surface. The adults of some of these species also spend a large proportion of time in the upper water column.

Bibliography

1. **National Research Council (2005)***Oil Spill Dispersants: efficacy and effects.* http://www.nap.edu/catalog/11283.html : National Research Council, 2005.

2. **Shigenaka (2003)** *Oil and Sea Turtles: biology, planning and response.* http://response.restoration.nooa.gov/book_shelf/35_turtle_complete.pdf : NOAA Office of response and Restoration

3. **Neff J (2005)** Chapter 1. Composition and Fate of Petroleum and Spill-Treating agents in the marine environment. In: Geraci JR and St Aubin DJ (eds) *Synthesis of effects of oil on marine mammals.* Minerals Management Service OCS88-049

4. **Anderson JW et al (1974)** *Characteristics of dispersions and water-soluble extracts of crude and refined oils and their toxicity to estuarine crustaceans and fish.* s.l. : Marine Biology Vol. 27 (1): 75-88.

5. **Fucik K (1994)** *Dispersed oil toxicity tests with species indigenous to the Gulf of Mexico.* Minerals Management Service Publication 94-0021

6. . **Fuller C et al (2004)** *Comparative toxicity of oil, dispersant, and oil plus dispersant to several marine species***.** Environmental toxicology and chemistry Vol. 23(12):2941-2949.

7. **Beiras R and L Saco Alvarez (2006)** *Toxicity of seawater and sand affected by the Prestige fuel-oil spill using bivalve and sea urchin embryogenesis bioassays.* Water air and soil pollution Vol. 177: 457-466.

8. **Benfield and Shaw (2005)** *Potential spatial and temporal vulnerability of pelagic fish assemblages in the Gulf of Mexico to surface oil spills associated with deepwater petroleum development.* US Dept Interior, MMS Gulf of Mexico OCS region, New Orleans. OCS MMS 2005-012.

9. **Davis (2002)** *Cetacean habitat in the northern oceanic Gulf of Mexico.* Deep Sea Research I: Oceanographic research papers Vol 49(1): 121-142.

10. **Geraci JR and St Aubin J (eds) (1988)** *Synthesis of effects of oil on marine mammals .* Atlantic OCS region : Minerals Management Service OCS 88-049

11. **Briggs KT, ME Gershwin and DW Anderson (1997)** *Consequences of petrochemical ingestion and stress on the immune system of seabirds.* ICES journal of Marine Science Vol. 54(4): 718-7258.

12. **Albers PH (2006)** *Birds and PAHs.* Avian and poultry biology review, Vol. 17(4): 125-140.

13. **Lance BK, et al. (2001)** *An evaluation of marine bird popualation trends following the Exxon Valdez oil spill in Prince William sound Alaska.* Marine Pollution Bulletin Vol. 42(4): 298-309.

14. **Culbertson JB et al (2007)** *Long term biological effects of petroluem residues on fiddler crabs in salt marshes.* Marine Pollution Bulletin Vol. 54(7): 955-962.

15. **Donkin P et al (2003)** *Toxic effects of unresolved complex mixtures of aromatic hydrocarbons accumulated by mussels, Mytilus edulis, from contaminated field sites.* Envrionmental science and technology Vol. 37(21): 4825-4830.